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ISS Human Research Facility (HRF) acoustics

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1.0 INTRODUCTION

Acoustic issues of the Human Research Facility payload rack 1 (*Figure 1.*) and its degree of compliance with NASA International Space Station (ISS) SSP57000 requirements were not fully known or predicted in the early design period until first flight hardware rack was completed in middle of the 1999. NASA JSC ISS acoustics engineering and HRF designers conducted joint tests and acoustics surveys on HRF acoustics compliance at the Johnson Space Center (JSC). Due to HRF flight hardware availability, the acoustics surveys for compliance were first conducted on the High Fidelity Mockup (HFM) training rack. The HFM was verified to have the same acoustical characteristics as the flight hardware rack by acoustic tests performed in the JSC HRF clean room. Primary acoustics test results on the HRF training rack revealed high continuous noise levels excessive to the NC-40 sound pressure level requirement in the SSP 57000 specification. Acoustical non-compliances were found on all sides of the rack. ISS Acoustics Engineering worked with HRF designers to conduct detail noise source analysis and rack configuration reviews to search for possible acoustical treatments to the HRF rack.

The HRF Rack is an ISS facility class rack designed to accommodate multiple sub-rack payloads. Through noise surveys and analysis, the noise levels were mainly dependant on the number of the activated common fans in the HRF rack. The HRF Ultrasound payload contains two common fans; the HRF Workstation, the HRF GASMAP Analyzer, the HRF Cooling Stowage Drawers (CSDs), and the HRF rack each contain one common fan. The HRF rack noise varied with operational modes; therefore the loudest noise level radiated when all sub racks or payloads were activated.

Based on noise source analysis and contributions to the overall level of the HRF rack, the ISS acoustics team studied various acoustic treatments and approaches to mitigate noise emissions. Through systematic acoustic tests, the design concepts, feasibility, functionality, and benefits of various acoustic noise reduction treatments were evaluated and quantified. Methods of noise reduction evaluated were the uses of acoustical absorption material lining, acoustical barrier lining, acoustical leakage sealing, acoustical curtains, and Helmholtz resonators. In addition to the passive acoustic control methods listed above, the rack's operational design changes were applied and evaluated. These design changes lead to the reductions of fan speeds from the above listed set. Each was altered and set during ground testing based on thermal cooling requirements. A combination of these concept designs were tested and found to be very efficient in the reduction of the HRF rack noise levels. These designs were recommended for final flight implementation.

2.0 ACOUSTIC TREATMENTS ENGINEERING EVALUATION AND FLIGHT IMPLEMENTATION

The HRF acoustical treatment development involved two steps: engineering testing/evaluations and analysis, and flight implementation of tested abatement designs.

2.1 Engineering Evaluation:

Extensive tests were performed on HFM training rack without any acoustical treatment. This established the HRF's baseline for acoustical designs and treatments. It was found that with all rack, sub rack, and payload systems operating, the HRF rack radiated an overall sound pressure level 66 dBA compared to the rack requirement of NC-40 with an overall level of 49 dBA. The rack was in excess of the NC-40¹ acoustic requirement of from 250 Hz to 4K Hz. The front surface of HRF rack was the highest noise radiation area.

Various acoustical reduction approaches were tested, which included lining Melamine acoustical foam and Bisco[®] barrier wrap. Bisco is a trade name for loaded silicon rubber Poron[®] HT-200. These acoustical materials are ISS approved materials and flight certificated. Foams were lined internally at HRF rack's back, both sides of walls, and the middle column section of the rack to maximize acoustic energy absorption. The Bisco acoustical barrier, 1.0 pound per square foot (psf.), was encased in a Nomex[®] pouch so that the Bisco was lined on one side of the Melamine foam. The addition of the Bisco between rack walls and the Melamine is to block noise out from the rack wall and also increased the Melamine foam's absorption efficiencies. These abatements demonstrated a very effective attenuation performance with foam/Bisco lining only, which induced an overall 4 to 5 dBA reduction from 250 Hz to 8Khz range.

In addition to HRF rack's internal acoustical treatments, some external acoustical suppression approaches were evaluated. A front acoustical curtain (lay-up) design made of the 1.0 psf Bisco wrap tested to be effective and showed an overall 9 to 10 dBA reduction at the loudest noise level on the front surface of the HRF rack. This was in addition to the use of Melamine foam in the rack. The excellent noise reduction performance of the HRF acoustical curtain tests also proved that the rack front had significant noise leakage concerns. *(Figure 2)*

2.2 Acoustical Design Flight Implementation:

Based on the previous design approaches with consideration of flight design limits and restrictions, the HRF final flight acoustic treatment consists of five different elements. The first element is an interior foam pouch. This pouch consists of ½ inch thick Melamine foam that is lined on one side with 1.0 psf-Bisco loaded vinyl and sewn into a Nomex pouch. The Nomex fabric encasing the pouch lining has minimal effect on impairing the foam's performance. Nomex is beneficial in the containment of any particulate matter that may separate from the foam over time.

Melamine is soundproofing foam that is extremely lightweight. It also has exceptional resistance to heat, low flame propagation and smoke. These properties, in addition to the exceptional sound absorbing qualities, make Melamine a prime choice for sound absorption. For the side and center columns both 1 inch and ½ inch thick foams were evaluated and implemented into the flight design. *(Figure 4)*

The center columns provide rail support for the interchangeable sub-payloads. This space allowed for the use of 1-inch thick Melamine foam without impinging on the thermal transfer properties of the rack. The 1-inch foam used in the center column was encased in the Nomex.

The side gaps contained ½ inch Melamine foam encased in the Nomex pouch. Several thicknesses of foam were evaluated on the side gaps of the rack. The ½-inch foam was chosen over the 1-inch thickness for two reasons: (1) The overall amount of noise reduction that was achieved by the 1-inch foam was not substantial enough when compared to the added heat build up it caused. The amount of noise reduction between the two thicknesses was only on the margin of 0.5 to 1 dB in most frequencies. (2) The additional ½ inch would have required the racks fans to operate at faster speed to assist in the thermal cooling. The pouches (as noted before) used in the side also contained a layer of 1.0 psf. layer of Bisco. The layer of Bisco is adhered to the external facing side of the Nomex pouch to provide additional transmission loss at the side of the rack.

In the back of the rack, the Melamine foam was added and shaped to meet the available space limitations. The back section of the rack contains all the rack specific avionics and cooling hardware. The 3 inch thick acoustical foam

used was shaped to fit around the control valves that supply the cooling water to the heat exchangers. This foam was lined with the Bisco barrier on the side closest to the racks exterior skin and encased in the Nomex pouch. The Bisco used in all HRF applications was 1.0psf. This increased mass of the material provides increased transmission loss, in addition to the noise attenuation from the foam, and was used whenever a foam pouch would be affixed to the exterior shell of the rack. (*Figure 5*)

The second element used, Elastofoam[®], is a gasket liner that adhered to the side and center posts on the front of the rack. Elastofoam consists of scores of individual, fine wires chemically bonded to soft, closed cell silicone sponge. This gasket would provide noise leakage sealing when a sub-rack payload is installed into the rack. The sub-rack would compress against the Elastofoam providing a noise tight seal.

The third treatment used were Delrin clips, which fit into the openings around the handles used to insert and remove the payload drawers. These clips were applied and used to block any noise that would leak through the small openings on the handles.

The fourth treatment used was a payload closeout made up of plastic and a soft gasket that seals the opening between two adjacent payloads. (*Figure 6*) Payload closeouts consisted of a material called Strip-N-Stick[®] that is manufactured and produced by Furon. Strip-N-Stick was adhered to a strip of aluminum for rigidity and encased in Nomex. The Nomex allowed for the Strip-N-Stick to make contact with the surface of the payloads. Because the Gasket material was used to seal between the inserted sub-rack payloads and the rack, Strip-N-Stick was used to seal between each adjacent sub rack. The use of the payload closeout alone provided 3.5 dB reduction at 2000 Hz.

The fifth approach measured and analyzed was the reduction of the common fan speeds. The HRF rack was equipped with water fed heat exchanger that provided for heat dissipation from the sub rack payloads. In addition, each payload contained a common cooling fan to assist the water heat exchanger. In some cases, a payload had more than one fan. The rack had a fan, as well, that was used for air circulation and smoke detection. All of the fans were EG & G DC Rotron 28-volt muffin fans that provided a free speed air delivery of 180 CFM at 5200 RPM per product specification. Through thermal analysis, it was determined that the speed of the fans could be reduced and still provide acceptable cooling for the rack. Limiting the voltage to 16 volts DC lowered the speed of each fan located in each of the cooling stowage drawers. This voltage limitation was also performed on the rack's common air circulation fan. Final flight configuration of the fans resulted in the voltage reduction of the common rack-cooling fan from 28 to 16 volts, both of the fans associated with the cooling stowage drawers from 24 to 20 volts, and the fan for the Workstation 28 to 16 volts. For one of the nominal operating configurations, Rack Only, the HRF rack utilizes a common fan to provide cooling and air circulation for smoke detection. Noise levels for this operation exceeded requirements when the fan operated at 20 volts and above. Lowering the voltage for this operating scenario to 16 volts, in addition to the other acoustical treatments, reduced the speed of the fan and resulted in meeting all but one of the center octave band requirements. The noise level reduction of the Rack Only and Rack with Workstation and Cooling Stowage Drawers is shown in (*Figure 7 and 7A*). These are two separate operational modes that are used for conducting experiments on board the ISS.

3.0 HRF ACOUSTIC VERIFICATION TEST

3.1 Measurement Environment

The HRF Flight Rack acoustics verification tests were conducted at the Johnson Space Center in building 14's EMI chamber in the spring of 2000. The EMI chamber used in testing was equipped with 10-inch pyramid wedges on the walls and the ceiling. The room's dimensions were 23 feet long, 18 feet across, and 10 feet high. To help reduce the background noise during measurements, the air handling systems were turned off for the building. Additionally, the ceiling vent for the EMI chamber was covered with foam to block noise passing through the duct.

3.2 Acoustical Instrumentation and Data Acquisition System

Sound pressure level measurements were made with a (type 1) Bruel & Kjaer model 2825 PULSE system. A test for 9 channels of simultaneous data acquisition was set up. Larson Davis 1/2 inch microphones and pre-amplifiers were used for sound pressure level collection.

3.3 Measurement Set-up

All nine microphones were setup at 0.6 meters away from the HRF rack per SSP 57000².

3.4 Measurement procedure

Acoustic measurements were taken for each operational configuration and some additional cases. For each operational condition, octave band sound pressure levels from 63 Hz and 8000 Hz bands were collected. A total of nine microphones were used surrounding the rack. Two microphones were located at the loudest points on the front face of the rack. Additionally, one microphone was located at the loudest location on the left, right, and backside of the rack. The rest of the microphones were set up in front of the center point of each individual payload 0.6 meters away.

4.0 TEST RESULTS

Verification testing of the rack was achieved through preliminary analysis and testing of the above-mentioned materials and acoustic principals. Using the foam pouches with the Bisco inserts in conjunction with the gasket seals, Delrin clips, payload closeouts, and controlling the operational voltages of the fans, it was possible to achieve significant noise reduction. Noise reduction varied in each frequency. (*Figure 8*) An Overall A weighted sound pressure level of the rack operating with all subsystems and payloads without acoustical treatment was reduced from 65.5 dBA to 55.6 dBA by using the full acoustic treatments. This is an overall reduction of 9.9 dBA. Noise levels were measured on the rack with all subsystems and payloads running to determine the maximum possible noise reduction. Actual operating conditions are in lower initial noise levels and fall below the NC-40 requirement in most octave bands. In cases where operating conditions exceed the continuous operating requirements, equal to the NC-40 curve, intermittent time limits are established based upon the overall dBA levels to control their operating durations. GASMAP flight operational noise levels from applying all the acoustic treatments and engineering controls are shown in (*Figure 9*). GASMAP operations did not comply with the octave bands requirements for continuous operation, therefore this hardware had to meet the intermittent time requirements. Operational time was increased from 3 hours to 8 hours due to the 8dBA reduction in the overall noise emission. Significant reduction was received for all operating modes thus increasing the amount of operational time allowed for use on the ISS.

5.0 CONCLUSIONS

Through the use of several acoustic design principles, it was possible to achieve significant noise reduction of the Human Research Facility Rack. Principles such as acoustic absorption, the use of barrier materials, sealing open holes that allow for leakage and engineering controls all used in conjunction, reduced the overall noise emissions. Even though some methods tested provided acceptable noise abatement, other limiting factors discouraged their usage in this specific application. This should not discourage their use in other application. All these principles evaluated are viable options for noise control and should be considered in future design and development of flight hardware for the International Space Station.

6.0 ACKNOWLEDGEMENTS

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7.0 REFERENCES:

¹“Leo L. Beranek, “Criteria for noise and vibration in communities, buildings, and vehicles,” Chap. 17 in *Noise and Vibration Control Engineering-Principles and Applications*, edited by Leo L. Beranek and Istvan L. Ver (Wiley, New York, 1992).

2 *Pressurized Payloads Interface Requirements Document*, Space Station Program Document SSP 57000 Rev E: November 2000.

[illegible]

HRF Rack#1 Acoustical Survey at Mic. #1

Center Band Frequency - Hz	NC-40	All Sys, Foam	All Sys, Foam + Curtian	All Sys, Curtian	All SYS
63	64	55	52	55	55
125	56	59	58	58	60
250	50	61	60	60	64
500	45	60	55	58	64
1000	41	57	50	50	61
2000	39	51	41	43	54
4000	38	48	37	40	52
8000	37	35	26	30	38
10000	49	61	57	58	65

Figure 2, Acoustic Design Performance Comparison



Figure 3. Acoustic Curtain

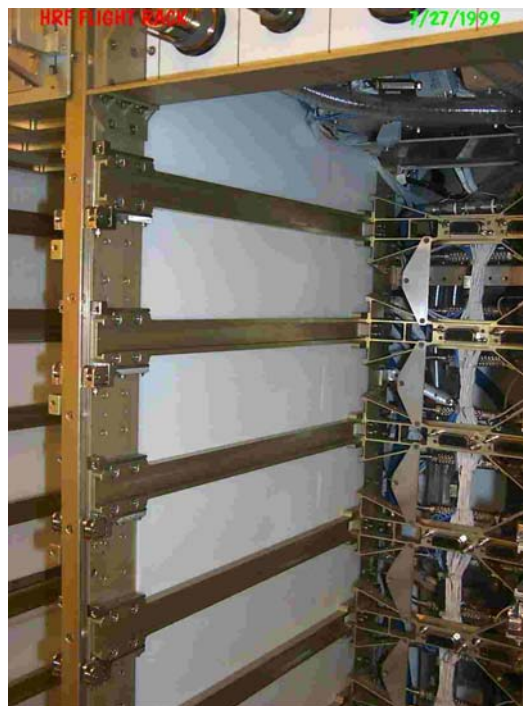


Figure 4. Melamine Inserts

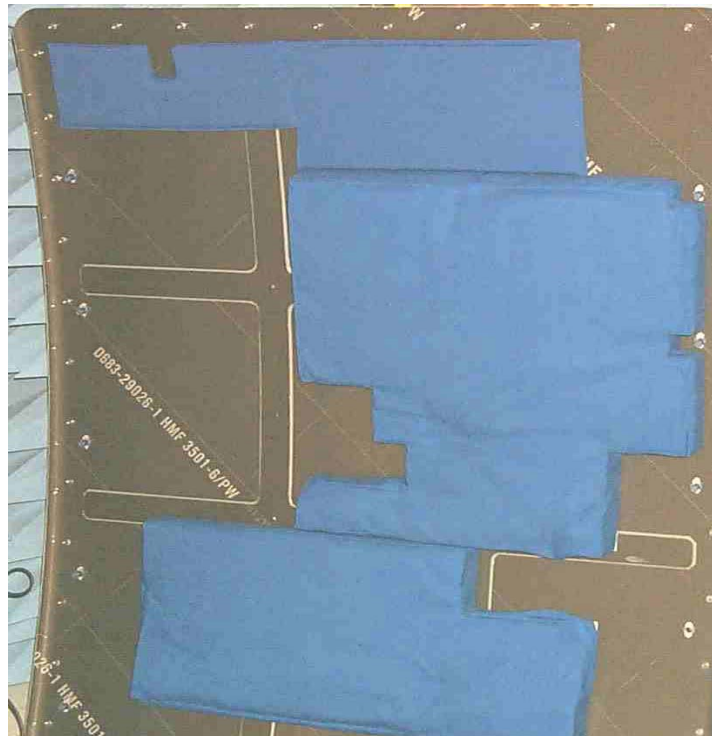


Figure 5. Pouch Attached to Rack Skin

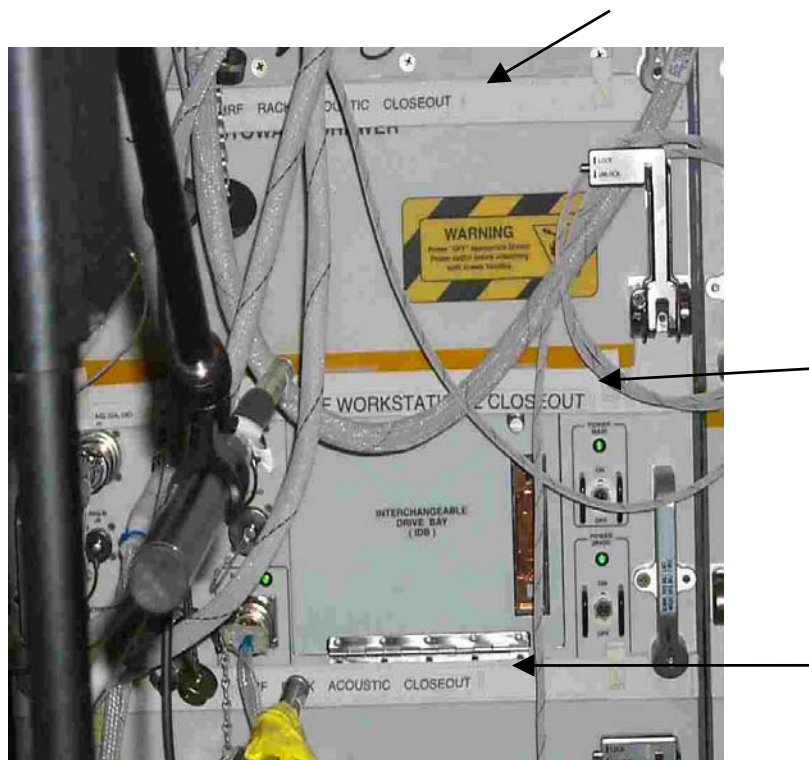


Figure 6. Payload Closeouts

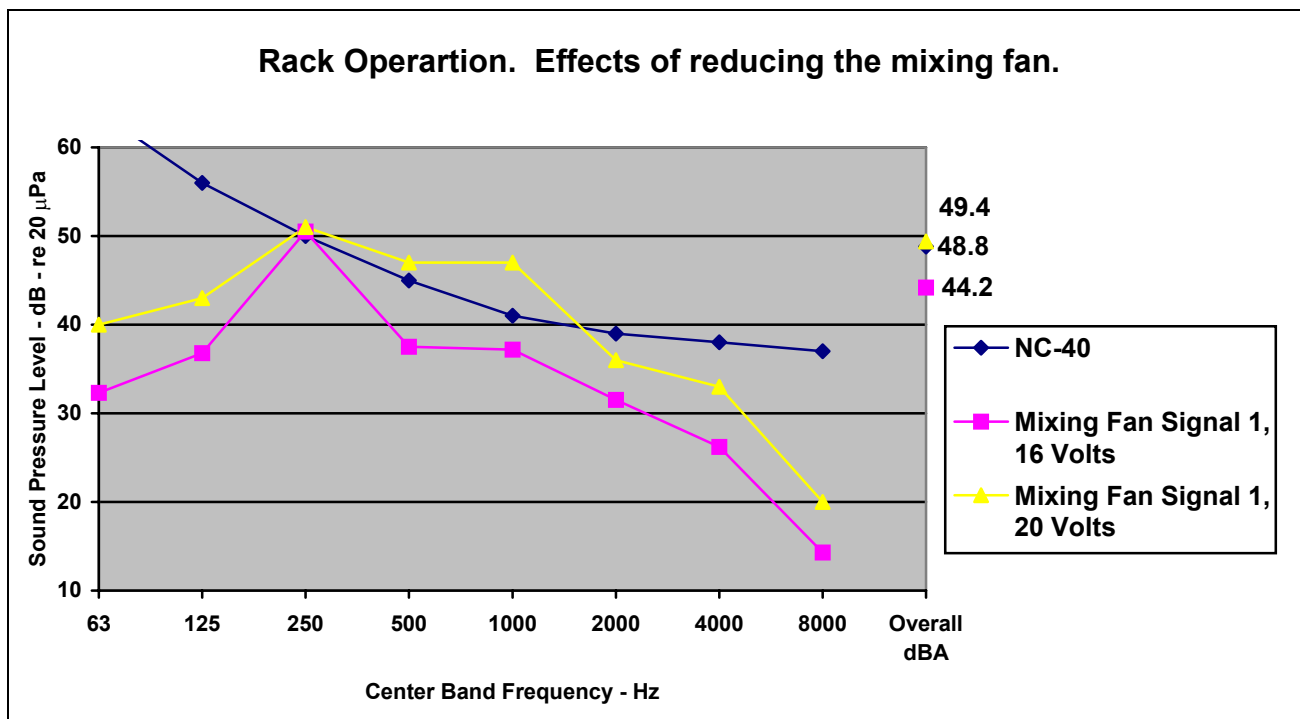


Figure 7.

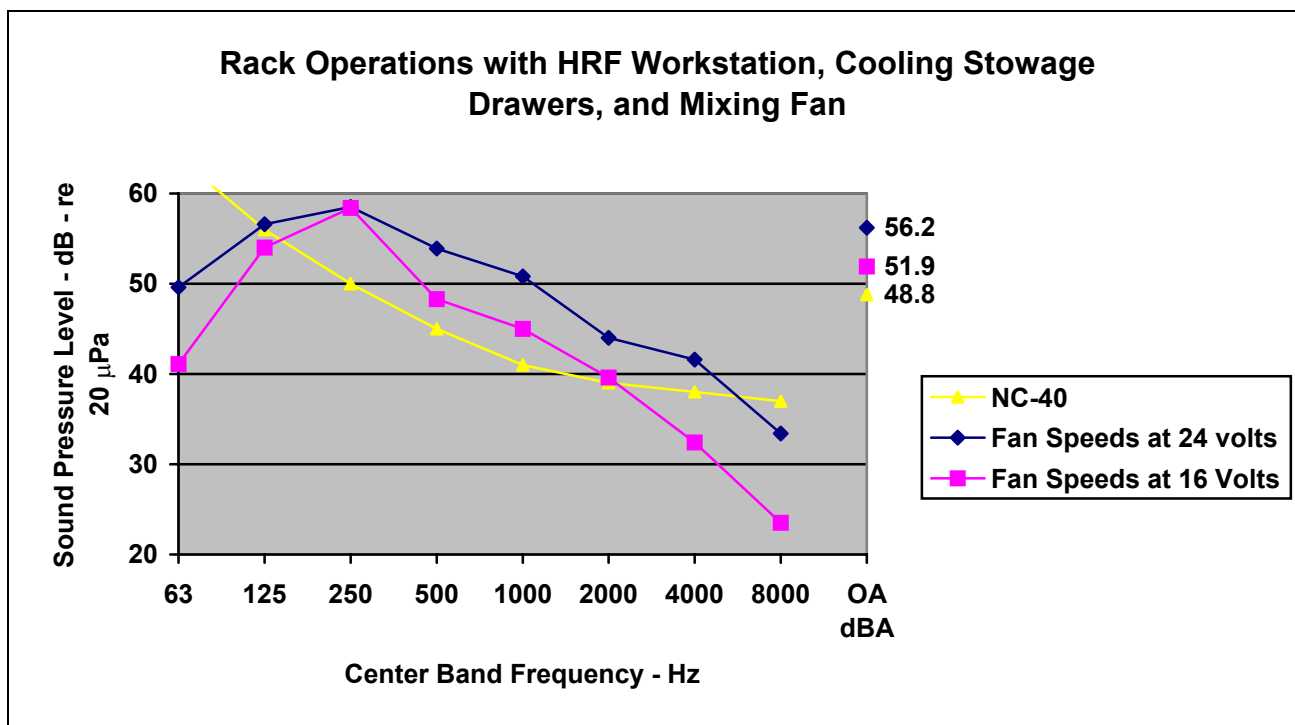


Figure 7A

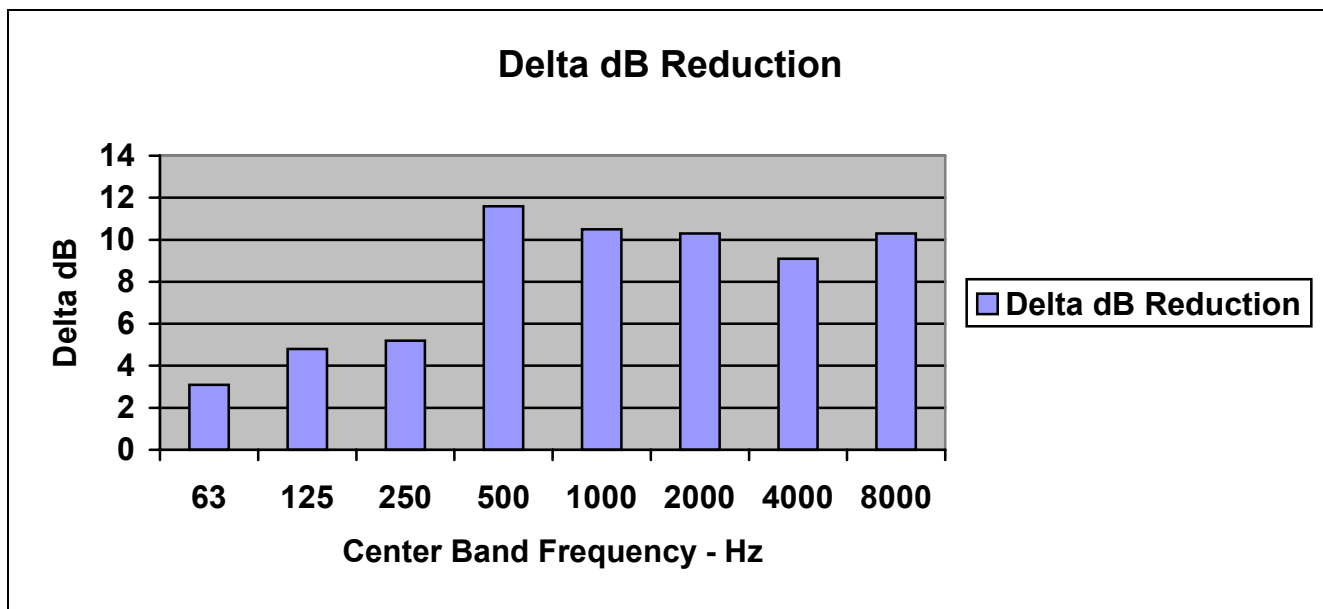


Figure 8. Final Flight Delta Reductions

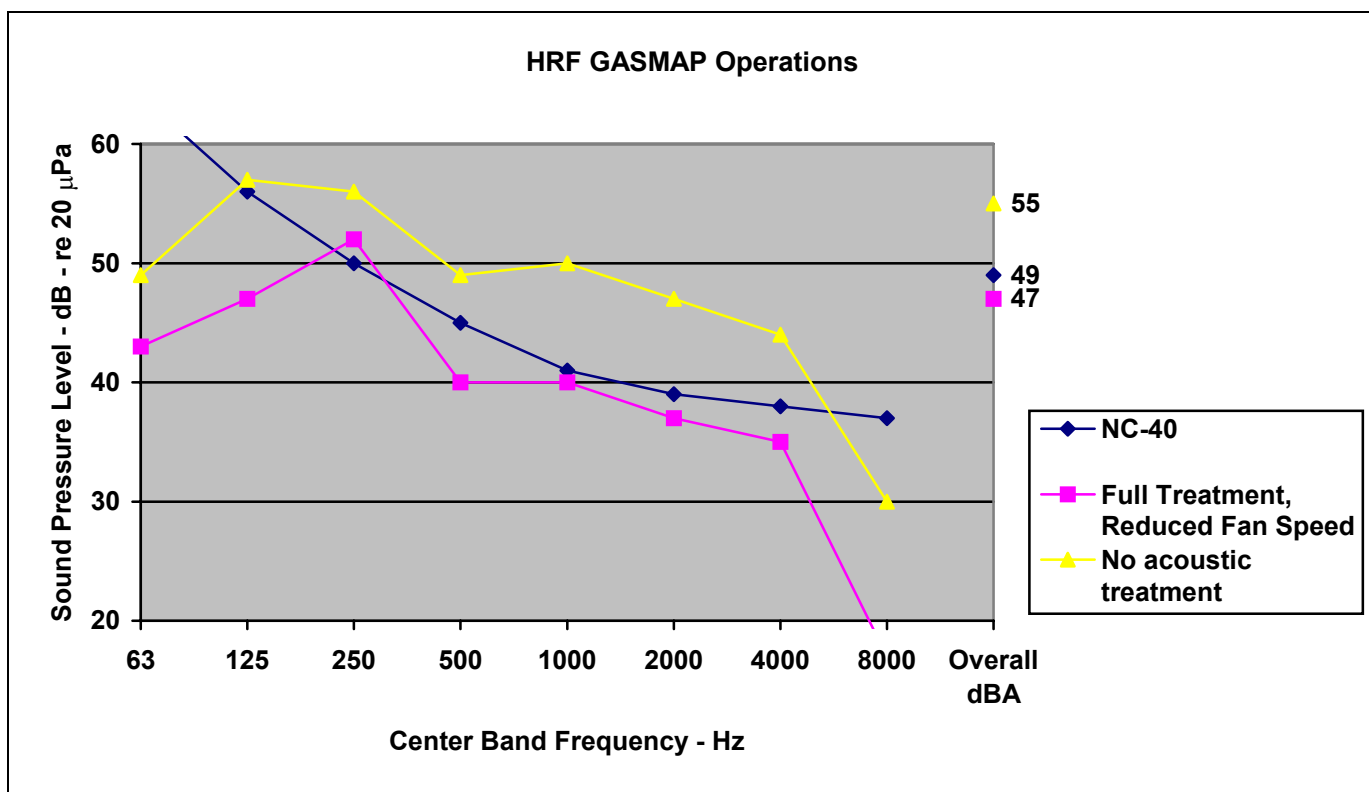


Figure 9. Flight Operation Noise Reduction